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Division VI

QUALIFICATION AND DESIGN OF ANCHOR CHANNELS IN NUCLEAR POWER PLANTS

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GENERAL REQUIREMENTS FOR FASTENINGS IN NUCLEAR FACILITIES

For nuclear power plants and nuclear facilities, the overriding protection goals are to be met such as

a) Control of reactivity b) Cooling of the fuel assemblies c) Confining of radioactive substances and d) limitation of radiation exposure (KTA-GS-70/ 2013).

Building structures and system components (KTA 2201.1/ 2011 or YVL B.2/ 2011) are to be designed regarding accidental actions which occur during abnormal operation or during incidents and very rare events. A distinction is generally made between internal (EVI) and external (EVA) actions.

The components and building structures, required for compliance with the protective goals, are defined as safety-related components and building structures (including structural members as parts of building structures). Consequently, safety-related fastenings are fastenings of components and structural members, which are safety-related in themselves or whose failure could affect safety-related components or structural members (see also classification according to KTA 2201.1 or YVL B.2). All safety-related components and building structures as well as safety-related fastenings require a seismic design considering the design basis earthquake (DBE). Therefore, safety-related fasteners, in contrast to "normal building construction", are to be qualified and designed for extra-wide cracks in the concrete according to the European guidelines (TR 049, DIN EN 1992-4).

In addition, other safety requirements of the nuclear standards e.g. DIN 25449 or the afcen code RCC-CW should be defined project-specifically and observed.

GERMAN STANDARDS FOR ANCHOR CHANNELS IN NUCLEAR FACILITIES

The safety concept, effects, dimensioning and construction for components made of reinforced and prestressed concrete in nuclear facilities can be found in the German standard DIN 25449. Particularly in requirement category A3, combinations with extraordinary effects with a low probability of occurrence ($\leq 10^{-4}$ / year) are defined.

For post-installed fasteners, the “DIBt-guideline for post-installed fasteners in Nuclear Power Plants and Nuclear Facilities” considers criteria for safety-relevant applications to meet extraordinary load combinations.

To cover the extreme cases of requirement category A3 from DIN 25449, crack widths $w_1 = 1.0$ mm and $w_2 = 1.5$ mm are considered, which are thus far above the values in conventional building construction.

For the qualification of anchor channels, as well as for anchor plates with headed bolts, the test requirements from the "DIBt-guideline" have been incorporated in other nuclear standards (afcen-code RCC-CW) and can be applied based on expert test reports (Expert report TU Dortmund). This procedure has been recognized practice for the use of anchor channels in nuclear facilities for many years.

Project-specifically, this approach was also supported by the building supervisory authorities (local state authorities and DIBt) by issuing approvals in individual cases.

EUROPEAN STANDARDS FOR ANCHOR CHANNELS IN NUCLEAR FACILITIES

There are currently neither harmonized European standards for the dimensioning of components made of reinforced and prestressed concrete (compared to DIN 25449) nor for the qualification of anchoring technology in nuclear facilities.

For the construction of new nuclear facilities, the regulations for "seismic performance categories" from DIN EN 1992-4 (table 1) are used for dimensioning and TR 049 for the qualification of the anchoring technology, which takes crack widths up to 0.8 mm into account.

Table 1: EN 1992-4, seismic performance categories for fasteners

Table C.1 — Recommended seismic performance categories for fasteners

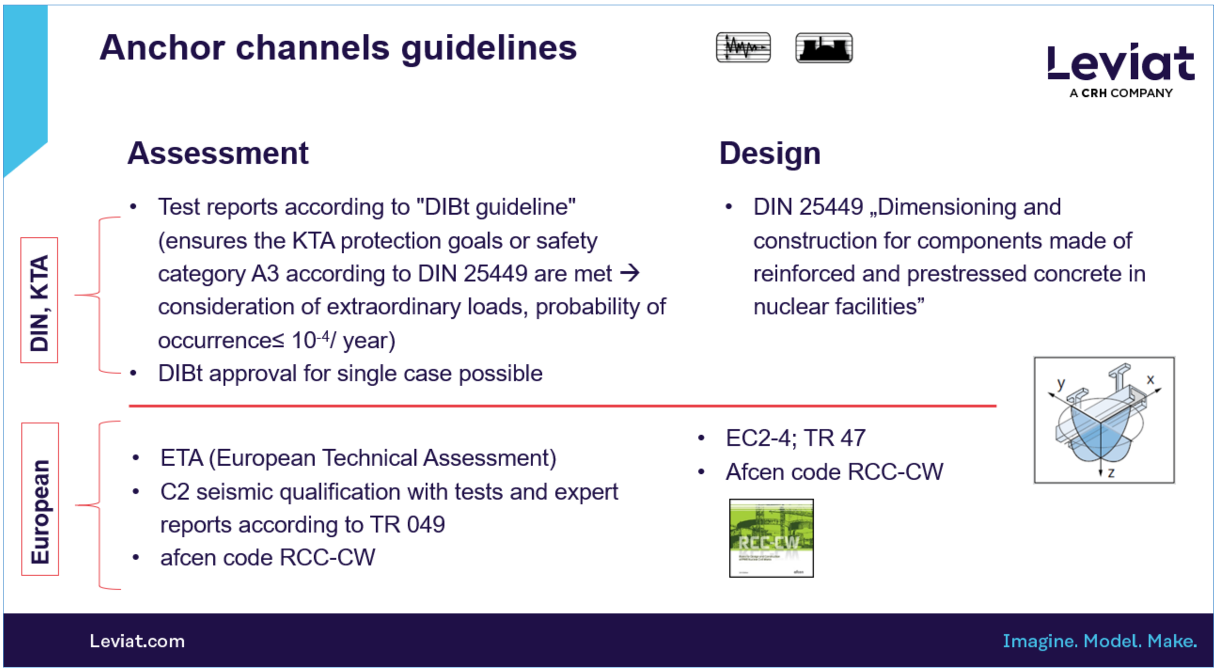
	Seismicity level[a]		Importance Class acc. to EN 1998-1:2004, 4.2.5			
1	Class	$a_g \cdot S^c$	I	II	III	IV
2	Very Low[b]	$a_g \cdot S \leq 0,05\,g$	No seismic performance category required			
3	Low[b]	$0,05\,g < a_g \cdot S \leq 0,1\,g$	C1	C1[d] or C2[e]		C2
4	> low	$a_g \cdot S > 0,1\,g$	C1	C2		

[a] The values defining the seismicity levels are subject to a National Annex. The recommended values are given here.
[b] Definition according to EN 1998-1:2004, 3.2.1.
[c] a_g = design ground acceleration on type A ground (see EN 1998-1:2004, 3.2.1),
S = soil factor (see EN 1998-1:2004, 3.2.2).
[d] C1 for fixing non-structural elements to structures (Type 'B' connections)
[e] C2 for fixing structural elements to structures (Type 'A' connections)

For international new construction projects, e.g. for the EDF, the regulations of the afcen standards must be observed. Afcen is an international association, with members are companies from the nuclear or conventional energy sector, producing up-to-date codes and practical rules for the design, construction and in-service inspection of components for use in industrial or experimental nuclear facilities. One of the codes, RCC-CW, considers the qualification of anchor channels either according to DIBt guidelines (crack widths up to = 1.5 mm) or according to TR 049 (crack widths up to = 0.8 mm, C2). Table 2 summarizes the current assessment and design guidelines for anchor channels.

This enables the planners and builders of new nuclear facilities to consider project-specific principles for the design and qualification of anchor channels.

Table 2: Overview regarding assessment and design guidelines for anchor channels



HALFEN ANCHOR CHANNELS, ASSESSMENT AND QUALIFICATIONS

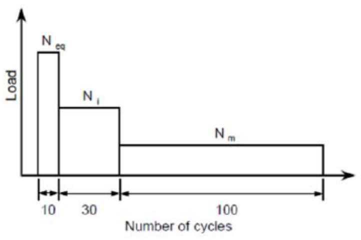
Independent on the specified guideline for extraordinary load cases, a prerequisite is the qualification of the anchoring product under "normal" conditions. For the qualification and assessment of anchor channels the European Assessment Document EAD 330008-03-0601 (EOTA) and the American Acceptance Criteria AC232 (ICC-ES) are available and recognized. Both documents are mostly aligned in regard to the procedures and requirements for the testing under static tension and shear loads perpendicular and in the direction of the channel axis. In total eleven test series are described to determine the load capacities for different failure modes and the product specific factors influencing the concrete or steel capacity. These values are published in the European Technical Assessment (ETA) or ICC-ESR and are used for the design.

Besides the static load cases, the current EAD additionally covers the qualification for fatigue (tension loads) and fire resistance (tension and shear loads perpendicular to the channel axis), while AC232 deals with seismic. Comparing the requirements for the seismic qualification of anchor channels according to AC232 with similar European guidelines (e.g. EOTA TR 049) the described load history and related load levels for the simulated seismic load cycles are comparable to the specifications used for seismic performance category C1 (table 3).

If the general qualification procedure for seismic performance category C2 according to EOTA TR 049 (table 4) can be applied to other anchoring systems, a qualification and assessment for anchor channels is feasible. This approach was used for a test campaign with HALFEN serrated anchor channels HZA-PS 53/34. In the case of anchor channels a differentiation for shear loads perpendicular and in direction of the channel axis is necessary.

Table 3: excerpt from AC232, test procedure for seismic qualification of anchor channels

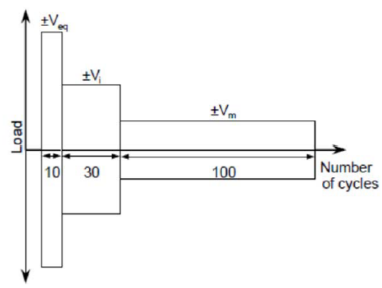
Test no.	Test ref.	Test description	f_c	Δ_w	Minimum no. of test
[-]	Section in Annex A	[-]	psi [N/mm²]		[-]
					Seismic Tests
12	7.12	Seismic tension	Low	0.020 (0.5)	5
13	7.13	Seismic shear perpendicular to the channel profile	Low	0	5
14	7.15	Seismic shear in longitudinal channel axis	Low	0.020 (0.5)	5



$$N_{eq} = 0.5 N_{o,l;}$$

$$N_m = \frac{N_{eq}}{2}$$

$$N_i = \frac{N_{eq} + N_m}{2}$$



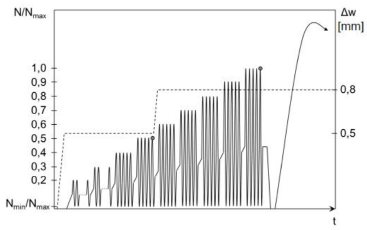
$$V_{eq} = 0.5 \cdot V_s$$

$$V_m = \frac{V_{eq}}{2}$$

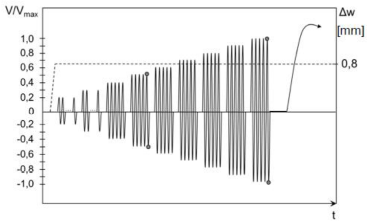
$$V_i = \frac{V_{eq} + V_m}{2}$$

Table 4: excerpt from EOTA TR 049, test procedure for seismic performance category C2

Test no.	Purpose of test	Concrete	Crack width Δw [1] [mm]	Minimum number of tests [2]
C2.1a	Reference tension tests in low strength concrete	C20/25	0,8	5
C2.1b	Tension tests in high strength concrete	C50/60	0,8	5
C2.2[3]	Reference shear tests	C20/25	0,8	5
C2.3	Functioning under pulsating tension load	C20/25	0,5 ($\leq 0{,}5 \cdot N/N_{max}$) [4] 0,8 ($> 0{,}5 \cdot N/N_{max}$)	5
C2.4	Functioning under alternating shear load	C20/25	0,8	5
C2.5	Functioning with tension load under varying crack width	C20/25	$\Delta w_1 = 0{,}0$ [5] $\Delta w_2 = 0{,}8$	5



N/N_{max}	Number of cycles	Crack width Δw [mm]
0,2	25	0,5
0,3	15	0,5
0,4	5	0,5
0,5	5	0,5
0,6	5	0,8
0,7	5	0,8
0,8	5	0,8
0,9	5	0,8
1	5	0,8
SUM	75	



$\pm V/V_{max}$	Number of cycles	Crack width Δw [mm]
0,2	25	0,8
0,3	15	0,8
0,4	5	0,8
0,5	5	0,8
0,6	5	0,8
0,7	5	0,8
0,8	5	0,8
0,9	5	0,8
1	5	0,8
SUM	75	

Hot-rolled serrated anchor channels with matching serrated channel bolts are suitable to transfer tension and shear loads perpendicular and in the direction of the channel axis. The ability to transfer loads from arbitrary directions make them a preferred anchoring solution for seismic applications. HALFEN hot-rolled serrated anchor channels have been tested under static, fatigue and seismic loading as well as fire exposure.

In general, anchor channels with sufficient anchor head size forming a mechanical interlock with the surrounding concrete are less sensitive to cracks with larger width as applied in seismic qualification tests. Simulated seismic tension tests with HALFEN serrated anchor channel HZA-PS 53/34 (Figure 1) showed no relevant reduction in load capacity after successful completion of the simulated seismic tension cycles and determination of the residual tension capacity for seismic performance category C1 as well as for C2. This was also the case in the test series with tension load under varying crack width (seismic performance category C2). While the behaviour under cyclic tension load might be similar for other types of headed anchors, the transferability of the presented results with tension load under varying crack width would need further verification.

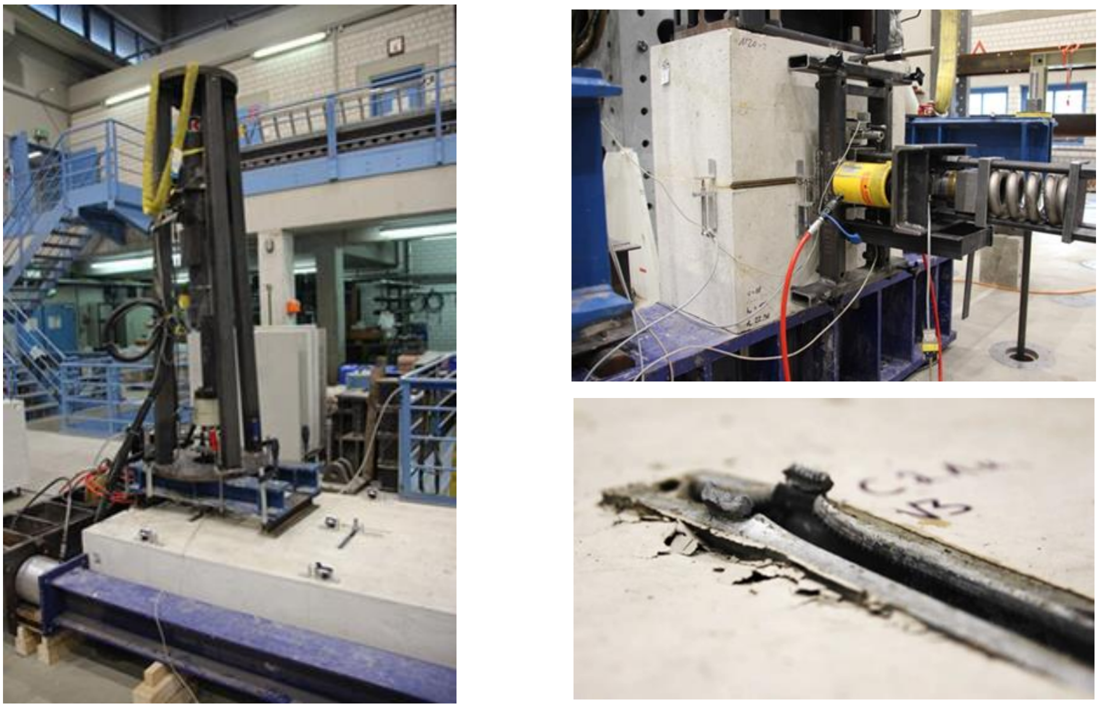


Figure 1: test set-up with HZA-PS 53/34 for seismic performance category C2 (tension) and typical failure mode in residual tension test

Test results with hot-rolled serrated anchor channels under simulated seismic shear load cycles according to seismic performance category C1 also did not show any relevant reduction in load capacity. For shear loads perpendicular as well as in direction of the channel axis the simulated seismic shear load cycles were successfully completed and the residual shear capacity reached the required level.

With the increased requirement on the load level for the simulated seismic shear load cycles for seismic performance category C2, test results with HALFEN serrated anchor channel HZA-PS 53/34 showed a reduction in load capacity compared to the values under static loading.
For the tests with simulated seismic shear loads perpendicular to the channel axis, a failure of the channel bolt close to the final load cycle were observed, leading to a repetition of the test series with reduced load level of the simulated seismic shear cycles. The required reduction resulted in appr. 20 %.

For the tests with simulated seismic shear loads in the direction of the channel axis, a failure occurred in the connection between channel lips and channel bolt (serration of the channel lips). In this case a reduction of appr. 40 % was necessary for a successful completion of the simulated seismic shear cycles and sufficient residual shear capacity.

In all test series the requirement for the deformation criteria was by far not decisive, demonstrating small displacements under seismic loading (Figure 2).

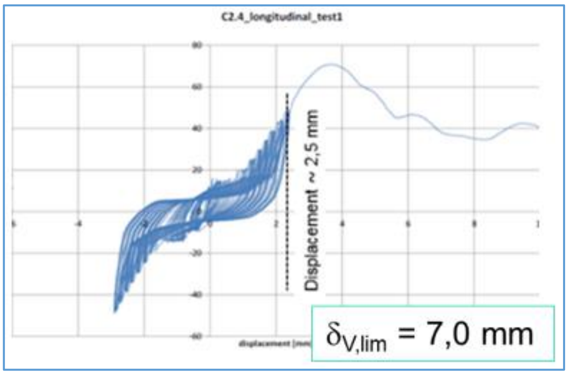


Figure 2: deformation criteria and test result

In the presented test campaign simulated seismic tests for seismic performance category C2 with HALFEN serrated anchor channels HZA-PS 53/34 were performed in accordance with the test procedure described in EOTA TR 049. The results show that while the influence of the crack width on the load bearing capacity of the anchor channel under tension load is neglectable, a reduction under simulated seismic shear loads due to the elevated load level can be observed (see table 5). With the necessary reduction of the seismic shear loads a successful completion of the simulated seismic load cycles and residual load capacity was possible.

Table 5: Load capacities for HALFEN HZA-PS 53/34

Anchor channel	HZA-PS 53/34	
	static loads and seismic performance category C1	seismic performance category C2
	[kN]	
min $N_{Rd,s}$	45	45
min $V_{Rd,s,y}$	56	43
min $V_{Rd,s,x}$	27	16

CONCLUSIONS

For the compliance of the protective goals of nuclear power plants, safety-related components and building structures as well as safety related fastenings are defined with the consequence to consider extraordinary loads respectively seismic effects.

Seismic tests for seismic performance category C2 with HALFEN serrated anchor channels HZA-PS 53/34 were performed in accordance with the test procedure described in EOTA TR 049.

The results show that while the influence of the crack width on the load bearing capacity of the anchor channel under tension load is neglectable, a reduction under simulated seismic shear loads due to the elevated load level can be observed.
With a reduction of the seismic shear loads a successful completion of the simulated seismic load cycles and residual load capacity was possible.

The test procedure described in EOTA TR 049, specifically applied for anchor channels, is also basis of the nuclear standard “afcen-code RCC-CW” with crack widths up to 0.8 mm for seismic performance category C2.

This enables the planners and builders of new nuclear facilities to consider project-specific principles for the design and qualification of anchor channels.

REFERENCES

Block, K, Kim, U. - Evaluation report 09.05.18-E (2010): „Anchor channels HZA-PS for use in nuclear power plant and nuclear facilities", Dortmund.

DIBt-Guideline (2010): "Guideline for Fastenings with Anchors in Nuclear Power Plants and Nuclear Facilities", Deutsches Institut für Bautechnik, Berlin.

DIN 25449 (2015): "Reinforced and prestressed concrete components in nuclear facilities – Safety concept, actions, design and construction", Deutsches Institut für Normung (DIN), Berlin.

ETAG 001 Annex E (2013): "Guideline for European technical approval of metal anchors in concrete, Annex E: Assessment of metal anchors under seismic actions", European Organisation for Technical Approval, Brussels.

DIN EN 1992-4: "Eurocode 2: Design of concrete structures — Part 4: Design of Fastenings for Use in Concrete", European Committee for Standardization (CEN/TC 250), Brussels.

KTA 2201.1 (2011): "Design of Nuclear Power Plants against Seismic Events; Part 1: Principles", Safety Standard of the Nuclear Safety Standard Commission (KTA), Salzgitter.

KTA 2201.3 (2012): "Design of Nuclear Power Plants against Seismic Events; Part 3: Building structures", Safety Standard of the Nuclear Safety Standard Commission (KTA), Salzgitter.

KTA-GS-80 (2013): "Application of Fastenings with Anchors in Nuclear Power Plants", Status Report of the Nuclear Safety Standard Commission (KTA), Salzgitter.

TR 049 (2016): „Post-installed fasteners in concrete under seismic action ", European Organisation for Technical Approval, Brussels.

YVL B.2 (2011): "Guide - Safety Classification of Systems, Structures and Components in Nuclear facilities", Finnish Radiation and Nuclear Safety Authority (STUK), Helsinki.

AFCEN-code RCC-CW (2021): "Rules for design and construction of PWR nuclear civil works", afcen, Paris.

AC232 (2019). Acceptance criteria for anchor channels in concrete elements. International Code Council Evaluation Service, Inc. (ICC-ES), Whittier, California.